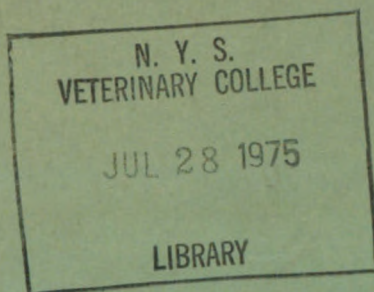


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**PREVENTION AND CONTROL
OF
VECTOR PROBLEMS
ASSOCIATED WITH
WATER RESOURCES**

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PREVENTION AND CONTROL OF VECTOR PROBLEMS
ASSOCIATED WITH WATER RESOURCES

1965
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UNITED STATES DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
Bureau of Laboratories
Vector-Borne Diseases Division
Water Resources Branch
Fort Collins, Colorado

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PREVENTION AND CONTROL OF VECTOR PROBLEMS ASSOCIATED WITH WATER RESOURCES

INTRODUCTION

Great expansion in the development of water resources has occurred during the last two decades in an effort to meet the needs of the Nation's growing population. This expansion will undoubtedly continue at an accelerated rate in order to keep pace with increasing demands for water, particularly for irrigation agriculture and to meet the needs of rapidly growing industry. It is now recognized that a wide range of interests must be given full consideration in the development and utilization of water resource projects in order to assure maximum benefits to the greatest number of people. One of these interests involves the prevention and control of insects which create public health hazards.

This pamphlet is limited to discussions of the various aspects of vector problems of public health importance associated with water resource development. In these discussions, vectors are considered as species which carry human disease organisms or which affect man's comfort, mental equanimity, and economic welfare.

It has been repeatedly demonstrated that water resource projects, especially impoundments and irrigation developments, create insect-vector problems unless appropriate prevention and control measures are provided. The effective prevention and control measures that were developed and incorporated into the design, construction, and operation of TVA projects and other impoundments throughout the Southeast played a major role in suppressing malaria in this country. In contrast, relatively little attention has been devoted to the prevention and control of other types of vector problems associated with water resource developments. As a consequence, the rapid expansion of irrigation and other water resource projects has usually been accompanied by proportionate increases in aquatic habitats favorable for the production of insects of public health importance. Mosquitoes are the most important of these insects although other groups such as deer flies, horse flies, black flies, biting midges, and the non-biting chironomids are often involved.

The public health importance of insect problems associated with water resource developments is increasing due to (1) the rapid increase in populations in existing irrigated areas where little or no attention has been given to control or prevention of vectors, (2) man-made aquatic habitats created by construction of new projects, (3) the increasing exposure of man to insects of public health importance due to expanded public use of water-related recreational areas, (4) the development of

insecticidal resistance, and (5) public demand for a more healthful environment. It is therefore urgent that programs for the prevention and control of insect-vector problems keep pace with the various other matters involved in the development and utilization of water and land resources.

PUBLIC HEALTH AND ECONOMIC IMPORTANCE OF VECTOR PROBLEMS

Several groups of arthropods and rodents associated with the development and utilization of water resources may create serious public health and economic problems. These include species that are vectors of disease organisms and species that serve as reservoirs of these organisms or otherwise interfere with man's health and welfare.

Approximately a dozen species of mosquitoes of public health and economic importance may be produced in habitats associated with irrigation, impoundments, and other water resource developments. Encephalitis, commonly known as sleeping sickness or brain fever, is now the most important mosquito-borne disease in the United States. Mosquitoes obtain the encephalitis viruses from birds and then transmit them to other host animals including horses and humans. There are no effective chemotherapeutic measures known for preventing or treating human cases, and some individuals, particularly children, who recover from encephalitis often suffer permanent disability. Three principal types of mosquito-borne encephalitis occur in the United States. Eastern encephalitis (EE) occurs mainly in the Atlantic and Gulf States from New Hampshire to Texas, but sometimes extends as far inland as Wisconsin. St. Louis encephalitis (SLE) occurs chiefly west of the Mississippi River and in several of the Central States and Florida. The third type, Western encephalitis (WE), is confined primarily to the States west of the Mississippi River.

Culiseta melanura and several species of Aedes mosquitoes are believed to be involved in the transmission of EE. The principal vector of both WE and SLE in the Far West is Culex tarsalis, a mosquito which is widely distributed west of the Mississippi River. In the Central States, mosquitoes of the Culex pipiens-quinquefasciatus complex are believed to be important in the transmission of SLE. In Florida, Culex nigripalpus is recognized as a vector of SLE. Aedes and other mosquitoes may also be involved as secondary vectors of encephalitis. Both Western and St. Louis encephalitis are endemic in many western areas, and outbreaks of WE among horses and of WE and SLE among humans have been rather widespread. In recent years, outbreaks of encephalitis have occurred in irrigated areas in the Texas High Plains (1956-1964), Intermountain States (1957 and 1964), Lower Rio Grande Valley (1957), Utah and New Mexico (1958), and Wyoming (1960).

The occurrence of malaria outbreaks as a result of improperly prepared reservoirs in the Southeastern States is well documented. Malaria has also been associated with irrigation in several States including

California, New Mexico, Texas, and in the rice-growing areas of the Mississippi Delta. This disease has been almost eradicated from the United States; and at present, there is no significant malaria transmission anywhere in the Nation. The malaria vectors (Anopheles quadrimaculatus in the East and Anopheles freeborni in the West) are still prevalent in some areas where favorable habitats are present. These mosquitoes constitute a potential hazard for the establishment of new foci of malaria transmission, particularly in situations where the disease may be reintroduced from foreign countries. This was well illustrated at Lake Vera in California during the summer of 1952, where 35 cases of malaria occurred among Camp Fire Girls. The source of their infections was traced to a soldier who had an attack of malaria while camping at the lake.

Aedes vexans, Aedes dorsalis, Aedes nigromaculis, and several other mosquitoes which cause severe biting annoyance to man and domestic animals are produced in habitats associated with irrigation and other water resource projects. These mosquitoes often create public health problems aside from the transmission of specific diseases. Such health hazards are illustrated by the results of surveys made by the U. S. Public Health Service in irrigated areas in northern Montana. In three-fourths of the families surveyed, mosquitoes severely annoyed both adults and children and interfered with their normal outdoor activities during the summer months. Mosquito bites caused some degree of injurious reaction in 8 out of 10 people interviewed; and in one section, 40% of the individuals examined by the physician showed evidence of secondary infection of mosquito bites. Some individuals, particularly children, frequently required medical attention and sometimes even hospitalization for treatment of secondary infections and allergic reactions caused by mosquito bites.

In addition to their public health importance, mosquitoes often create other serious problems in both rural and urban areas. Their vicious biting reduces the efficiency of farm workers and sometimes hinders the harvesting of crops. Dense populations of attacking mosquitoes have been reported to kill livestock. The constant attacks of even moderate populations of these insects may reduce the vitality of farm animals and prevent proper feeding, thereby causing reduced weight gains and lower milk and egg production. Mosquitoes are vectors of encephalitis, anaplasmosis, fowl pox, and several other important diseases of animals. These diseases kill large numbers of farm animals each year. Together, mosquito annoyance and mosquito-transmitted diseases undoubtedly result in losses of millions of dollars to farmers every year.

Large numbers of biting mosquitoes also cause serious economic losses by reducing the efficiency of industrial workers, lessening the value of real estate, restricting outdoor recreational activities, and reducing attendance at outdoor business establishments such as drive-in theaters and eating places.

The economic magnitude of the irrigation mosquito problem is illustrated by expenditures for abatement of these insects. For example, in California over \$6 million is spent annually to control mosquitoes, and it has been estimated that at least twice this amount would be required to provide adequate control throughout the State. The major portion of this mosquito control is carried out in irrigated areas. Approximately \$200,000 is spent each year for mosquito abatement in a few irrigated areas in Utah. Many urban communities in other western irrigated areas spend large sums of money each season for chemical control to provide partial protection from mosquitoes. Individual families also spend sizable amounts of money each summer for household sprays, mosquito repellents, livestock sprays, and medicine for treatment of mosquito bites. The total cost of controlling irrigation mosquitoes, together with the other serious economic losses they cause, runs into many millions of dollars each year. Thus, mosquitoes are a major economic liability in many irrigated areas.

NATURE AND EXTENT OF VECTOR PROBLEMS

Vector problems primarily concern mosquitoes and their biology; however, other aquatic insects, terrestrial arthropods, or rodents are sometimes involved.

Biology of Mosquitoes

This discussion is intended to provide only basic information concerning some of the more pertinent biological characteristics of mosquitoes commonly associated with water resource developments. These mosquitoes represent 4 important genera or groups: Anopheles, Culex, Aedes, and Psorophora. All mosquito species have 4 distinct stages in their life cycle: the egg, the larva ("wiggler"), the pupa ("tumbler"), and the adult (Fig. 1). A characteristic common to all mosquitoes is that they live in water continuously from the time the eggs hatch until the adults emerge. The aquatic stages generally occur in shallow water with an abundance of vegetation and flotsam and where they are protected from wave action. They do not occur in the deep open waters of lakes, ponds, or streams.

On the basis of egg-laying habits, mosquitoes may be divided into temporary-water and permanent-water species. The Aedes and Psorophora are temporary-water breeders which deposit their eggs on the moist soil of areas where surface water has receded. Hatching of the eggs is stimulated by subsequent floodings. The eggs may remain dormant for long periods, sometimes for several years if conditions are unfavorable for hatching. Normally, the eggs hatch more or less simultaneously soon after they are flooded. In contrast, the Anopheles and Culex usually lay their eggs on the surface of permanent and semi-permanent bodies of water. The eggs usually hatch within a few days after oviposition. For both the temporary-water and permanent-water

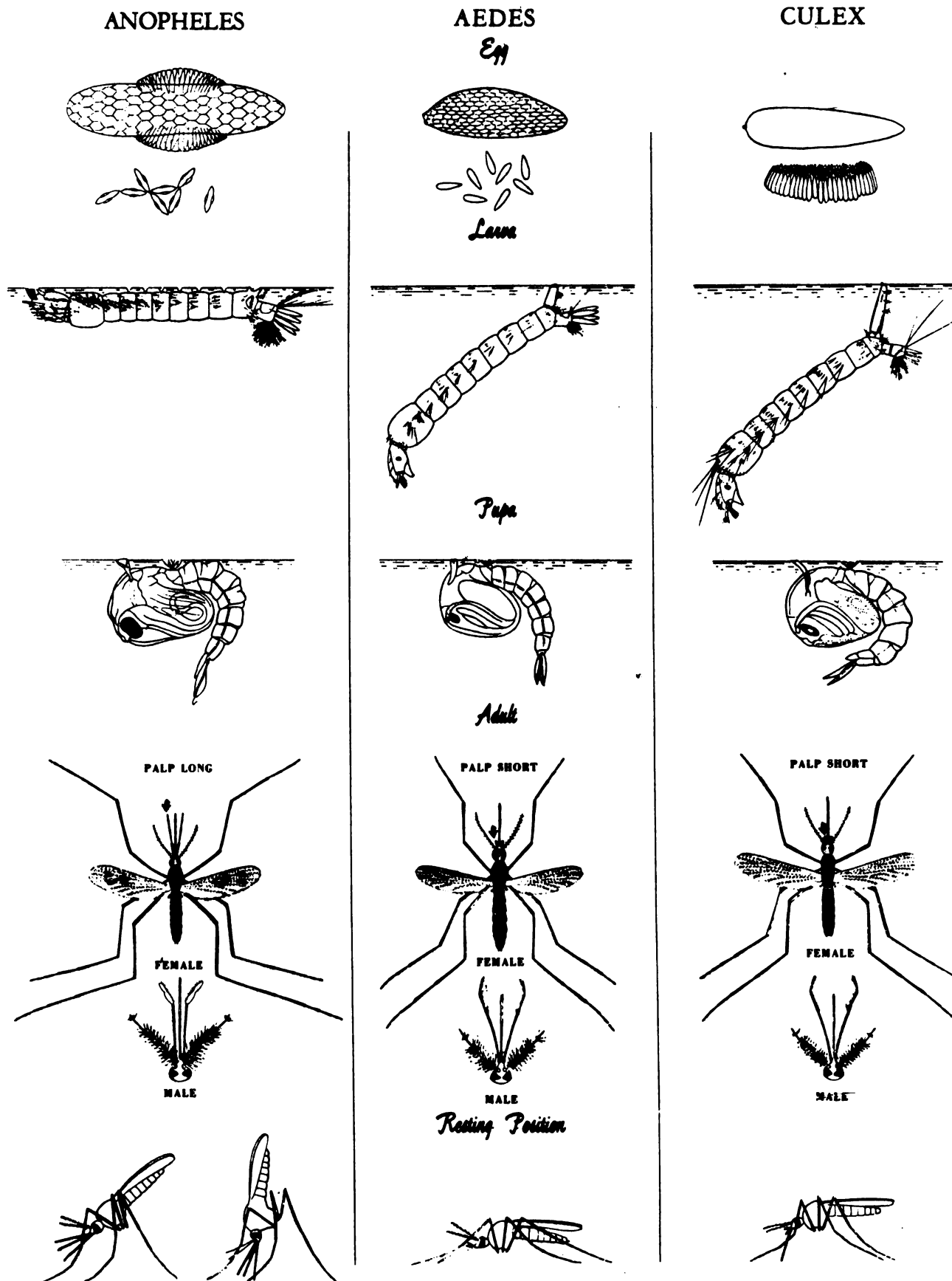


Figure 1. Characteristics of Anophelines and Culicines

mosquitoes, time between hatching of eggs and emergence of adults varies with species and environmental conditions, especially water temperature. Development of the aquatic stages may be completed in as little as 4 days in hot weather, while several weeks may be required in cool weather. Aedes and Psorophora mosquitoes generally develop more rapidly than the Anopheles and Culex.

Adult mosquitoes mate soon after emergence, and the females begin seeking blood meals, which most species require before laying eggs. The biting habits of adult mosquitoes vary with species. Anopheles and Culex mosquitoes feed mainly at night, while Aedes and Psorophora species feed both at night and in the daytime. Most species exhibit a peak of biting activity during the 1- or 2-hour period immediately after sundown. The Aedes and Psorophora species are aggressive and vicious biters of both man and livestock. Culex tarsalis, a vector of encephalitis, feeds readily on a wide range of hosts including man, wild and domestic birds, and livestock.

The flight range of mosquitoes varies widely with species and environmental conditions. The direction and distance of travel are greatly influenced by availability of food, shelter, and wind conditions. In many areas availability of food is probably the most important factor influencing the movement of mosquitoes. Generally, if an adequate food supply is close to the production sites, adult mosquitoes will not travel far from their sources. On the other hand, mosquitoes may travel several miles when adequate food supplies are not available nearer their larval habitats. The normal flight range of the Anopheles and Culex mosquitoes was formerly considered to be about 1 mile; however, recent studies have shown that certain species such as C. tarsalis may travel several miles. Most Aedes and Psorophora species are strong fliers and are known to range several miles from their larval habitats.

Other Aquatic Insects

Several other groups of aquatic insects may be produced in habitats associated with water resource projects in sufficient numbers to create public health and economic problems. Deer flies and horse flies (Tabanidae) are produced along the margins of impoundments and in seeps and marshes in irrigated areas. These insects are vicious biters of both man and livestock and are sometimes involved in the transmission of diseases such as tularemia and anthrax. Some species of small gnats of the family Ceratopogonidae are also vicious biters and often produce severe reactions and vesicular lesions. These gnats are produced in damp areas of many irrigated valleys as well as salt marshes and other wetland areas. In certain areas, black flies (Simuliidae) plague both man and livestock with their irritating and painful bites. They are normally produced in streams but sometimes occur in large numbers in irrigation conveyance systems. The small nonbiting midges (Tendipedidae) and the phantom midges (Chaoborinae) are another group of pestiferous

insects which may be produced in impounded water. These insects are attracted to lights in tremendous numbers and cause severe human annoyance. An example is the Clear Lake gnat, Chaoborus astictopus, which creates serious problems at the resort areas in Lake County, California.

Terrestrial Arthropods and Rodents

Each summer many millions of people who visit picnic sites, campgrounds, cabins, and other water-related recreational facilities along the shores of reservoirs are often exposed to terrestrial arthropods such as ticks, mites (chiggers), fleas, and flies as well as rodents including ground squirrels, rats, mice, and chipmunks. The public health importance of these arthropods and rodents involves a number of human diseases including Rocky Mountain spotted fever, Colorado tick fever, tularemia, relapsing fever, tick paralysis, typhus, plague, bacillary dysentery, and typhoid. In addition, the bites of certain arthropods cause considerable irritation, discomfort, and annoyance.

VECTOR PREVENTION AND CONTROL IN RELATION TO THE DEVELOPMENT AND UTILIZATION OF WATER RESOURCES

Water resource projects, especially impoundments and irrigation developments, invariably create a variety of man-made aquatic habitats favorable for the production of insects of public health importance. Experience has shown that if proper consideration is given to vector problems during the initial stages of project planning, adequate provision can be made for prevention or control measures that will minimize health hazards. It is therefore essential that vector prevention and control be planned and "built into" each new project and that it be compatible with the primary functions of the project, such as irrigation, navigation, hydroelectric power, and flood control. As a basic principle, the project sponsor, whether an agency, group, or individual, should be responsible for providing adequate vector prevention and control measures for water resource developments. For public-use developments, the planning, construction, and operating agencies or groups should have this responsibility; while for private developments, the land owner and/or operator should be responsible. The determination of public health requirements, including vector prevention and control measures, is usually the responsibility of the appropriate local, State, or Federal health agencies. These agencies should provide the construction and operating agency, group, or individual with appropriate plans and specifications for vector prevention and control.

A balanced program of naturalistic and source reduction measures adapted to the overall functions of the project provides the most effective control of vector problems, and over a period of years such measures are more economical than repetitive control measures.

Chemical control measures are often needed to supplement these measures because the water in certain types of aquatic habitats, such as rice fields, obviously cannot be eliminated. Likewise, other types of vector sources may be reduced in size but not completely eliminated. Insecticides are also employed to provide temporary control in emergency situations, such as encephalitis outbreaks. Chemical control in some sections of the country has been complicated by the fact that certain vector species have developed high levels of resistance to the chlorinated hydrocarbon and organophosphorus insecticides. The selection of an insecticide and its method of application should be based upon careful evaluation of a number of factors including cost, effectiveness, size and type of area to be treated, and its toxicity to fish, wildlife, domestic animals, and humans.

Vector problems associated with impoundments and the methods for solving these problems are usually different from those related to irrigation. These two types of water resource developments are the most important from the standpoint of vector problems and are discussed separately in the following sections. The discussions are limited primarily to the prevention and control of mosquitoes, the most important group of aquatic vectors associated with impoundments and irrigation. Many of the prevention and control measures for mosquitoes are equally effective against other aquatic vectors.

Mosquito Prevention and Control for Impoundments

Man-made impoundments range in size from large reservoirs covering thousands of acres to small farm ponds of less than an acre. Among the various types are multipurpose reservoirs built for power generation and/or flood control, navigation, irrigation, and related uses; municipal and industrial water supply impoundments; recreational lakes; fish and waterfowl impoundments; floodwater detention reservoirs; log storage ponds; farm ponds; and waste stabilization lagoons.

Mosquito-producing conditions are basically similar for the various types of impoundments but may vary greatly in magnitude. These conditions include emergent vegetation and/or floating debris in shallow water areas which are protected from wave action; undrained depressions, borrow pits, sloughs, marshes within the summer fluctuation zone, and rising or constant pool levels which cause the water to remain in the marginal vegetation for extended periods during the mosquito production season. It is almost axiomatic that reservoirs and ponds which are free of vegetation and flottage do not produce mosquitoes.

Malaria mosquitoes, A. quadrimaculatus, are frequently produced in impoundments which have protected shallow water areas with emergent vegetation and flottage. Such habitats may also produce several species of Culex mosquitoes, such as C. tarsalis, which like the Anopheles deposit their eggs on the surface of the water. Several species of

Aedes and Psorophora mosquitoes, which deposit their eggs on moist soil, are produced in marginal areas of reservoirs and ponds that have fluctuating water levels. Aedes vexans is one of the most common and widespread of these species.

It is often difficult to control mosquito production on impoundments which are not properly prepared prior to impoundage. The principal pre-impoundage measures for mosquito control include clearing of the basin; removal of vegetation from the fluctuation zone; and drainage for depressions, sloughs, and marshes within the summer fluctuation zone. Permanent shoreline improvement measures such as deepening and filling have been very effective in preventing mosquito production on TVA reservoirs throughout the Tennessee Valley. In order to preserve the effectiveness of permanent preventive measures, it is essential that reservoirs and ponds be properly maintained after they have been impounded. Of paramount importance is the fact that maximum mosquito control benefits from water level management can be realized only when impoundments have been properly prepared and maintained. Several phases of water level control, particularly flood surcharge, constant level pool, cyclical fluctuation, and/or seasonal recession can sometimes be adapted to various types of impoundments in order to minimize conditions favorable for mosquito production. A particular phase may be used to control vegetation and flottage which is favorable for mosquito production, or it may be used primarily to destroy mosquito larvae.

Conflicts sometimes arise between fish and wildlife conservation and mosquito control interests. They are frequently related to drainage and the use of insecticides and occasionally concern water level management and vegetation control (reservoir clearing). Experience with TVA impoundments has demonstrated that fish and wildlife conservation and mosquito control interests are not always antagonistic and that a cooperative approach to problems often results in the development of mutual benefits. As a general principle, wildlife conservation areas that have a high mosquito production potential should not be located within flight range of recreational areas or other human population centers.

Recreational areas, especially those with facilities for overnight occupancy, should be located along sections of the reservoir which have the lowest aquatic vector production. In selecting recreational sites, proper consideration should also be given to terrestrial vector problems. Thus, site selection for recreational areas should be based on a careful analysis of both aquatic and terrestrial vector problems. When necessary, full provision should be made for the prevention and control of both types of vector problems.

Mosquito Prevention and Control for Irrigated Areas

Some of the most rapid expansion in water resources development in recent years has been in the field of irrigation. This is particularly true in the 17 Western States where the total acreage of irrigated land increased from 17 million acres in 1939 to more than 30 million acres in 1959. Even in the East, supplemental irrigation is expanding rapidly. The rapid expansion in the development of irrigation, particularly in the West, has been accompanied by proportionate increases in the production of mosquitoes which are now creating serious public health problems in many areas.

Experience has shown that man-made aquatic habitats are usually responsible for excessive mosquito populations in irrigated areas. Natural mosquito sources occur in most irrigated areas, but usually the man-made sources are by far the most important. Mosquito production occurs in both "on-field" and "off-field" aquatic habitats. Conditions favorable to mosquito production are caused by poor irrigation and drainage practices including inadequate seepage prevention and control measures; poor land preparation; use of field layouts and irrigation methods that do not fit land, crops, and water supply; application of water in excess of crop requirements; inadequate drainage systems for removal and disposal of waste water; and poor maintenance of distribution and drainage systems. Mosquito sources on irrigated fields have been found to occur most often on fields used for pastures, hay meadows, and other close-growing forage crops on which water is frequently ponded long enough for mosquito larvae to mature. The greatest total acreage of "on-field" mosquito production for the entire West probably occurs on irrigated pastures, wild hay meadows, and rice fields. The major "off-field" mosquito sources include marshes, roadside ditches, borrow pits, wasteland, and various other undrained areas which are flooded by seepage and waste irrigation water.

The faulty irrigation and drainage practices that create man-made mosquito sources also result in serious soil and water problems such as excessive water losses, waterlogging, salt and alkali accumulations, damaged soil structure, leaching of plant nutrients, soil erosion, and reduced crop yields. The ultimate solution to mosquito problems associated with irrigation must be based upon source reduction measures which are aimed at preventing, eliminating, or reducing mosquito-producing areas. Practical measures for preventing and eliminating mosquito production associated with irrigation involve the use of good conservation practices which insure high crop yields without excessive water losses or decreased soil productivity. Experience has shown that the agricultural benefits derived from these practices usually greatly exceed the cost of applying them. The prevention and control of mosquitoes and mosquito-borne diseases is an additional benefit which greatly strengthens the justification for using good irrigation and drainage practices.

Legal Considerations in Vector Control

Almost every State has statutory provisions concerning the correction of nuisances or health hazards associated with insanitary conditions. Under these statutes, the abatement of public health problems associated with mosquitoes, flies, and other vectors is usually implied although it is not always specifically expressed. Most State and local health departments have general rules and regulations which may be used for the correction of public health hazards caused by various vectors. Effective regulation is generally provided when the extent of the problem is limited, when there are only a few violations, and when the property owners are able to undertake the necessary corrective measures. However, specific legislation is usually required for the prevention and control of serious problems that extend over large areas, such as mosquito problems in irrigated areas in the West.

Some 12 States in the South Central and Southeastern part of the Nation have adopted specific regulations that govern the conditions under which water may be impounded in order to minimize danger to public health. In most States, these regulations provide for reservoir clearing, drainage of marginal depressions, and periodic removal of vegetation after impoundage. Provision is also made for water level fluctuation and other supplemental control measures in several States. The regulations concerning impounded water were originally adopted for the control of malaria vectors; however, some States are broadening them to include other mosquitoes.

In recent years the need for specific legislation, authorizing formation of local mosquito control districts, has been recognized in many States throughout the Nation. Approximately half of the States now have legislation authorizing the establishment of county or district mosquito control organizations. This type of legislation has the advantage of permitting communities to meet local problems by organizing control programs that may be carried out on an area-wide basis. Such legislation has been found to be especially desirable in States where extensive mosquito problems occur, such as those associated with salt marshes and irrigation.

Vector Control Activities of Various Agencies

As previously indicated, various governmental agencies at the Federal, State, and local level are now concerned with vector control. The nature and scope of vector control activities carried out by these agencies, particularly those relating to water resource developments, are discussed in the following section.

Federal Agencies. Although all Federal development and/or operating agencies have an interest in safeguarding public health as related to their projects and programs, the consideration given to vector control

varies. Vector control programs of the Federal agencies may include the following types of activity: surveillance, research, technical assistance, and vector control operations.

The most extensive mosquito control operations have been carried out by the Tennessee Valley Authority and the U. S. Army Corps of Engineers on their impoundments. Emphasis has been given to the control of vectors of disease, particularly malaria mosquitoes (Anopheles quadrimaculatus).

The U. S. Public Health Service is responsible for developing and recommending procedures for the prevention and control of mosquitoes and other arthropods of public health importance associated with Federal water resource projects. In carrying out this responsibility, proposed plans for Federal water resource projects are studied to determine applicable vector prevention and control measures for incorporation into the design and construction of the project as well as control measures which should be used after the project is in operation. This activity is carried out in close cooperation with State health agencies, and the vector prevention and control recommendations are submitted jointly by the U. S. Public Health Service and the health department of the State in which the project is located. Because of limited funds and personnel available for this activity, vector evaluations and control recommendations usually are developed from an office review of the proposed plans, and field investigations are carried out on relatively few of the projects.

The Public Health Service also conducts investigations on the ecology and epidemiology of vector-borne diseases for the purpose of developing more effective vector prevention and control measures. A few studies have been conducted to determine the nature and extent of water resource vector problems, and to develop and field test chemical and source reduction measures for the control of encephalitis and other irrigation mosquitoes. Source reduction studies carried out on irrigated hay meadows in Montana in cooperation with the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture (USDA) were of particular importance. These investigations showed that improved soil and water management practices for certain types of irrigated hay meadows would eliminate mosquito production and increase crop yields 5- to 10-fold.

The Entomology Research Division of the Agricultural Research Service, USDA, carries out extensive research on agricultural insects. However, a branch of the Entomology Research Division is also concerned with investigations on insects affecting man and animals, and it devotes major attention to chemical control measures for mosquitoes, lice, and ticks.

The U. S. Fish and Wildlife Service has cooperated with mosquito control agencies in conducting research on mosquito breeding problems and on developing satisfactory solutions. The Service has conducted

pilot studies on the use of impoundments as a control measure for salt-marsh mosquitoes.

State Health Agencies. The State health departments in most States carry out some type of vector control activities, usually in conjunction with their environmental health programs. Agencies other than health departments have full responsibility for vector control in several States; and in a few cases, the responsibility is divided among several agencies. Vector control activities in the States vary widely depending upon the nature and extent of existing problems. They may include vector surveys; research on chemical and source reduction measures; educational, training, and promotional activities; technical assistance on vector problems; and in some cases participation in actual control operations.

Interests of the State departments of health in the prevention and control of insects of public health importance associated with water resource projects parallel those of the U. S. Public Health Service. In the past, several State departments of health, particularly those in the Southeast, have carried out a wide range of activities in connection with the control of malaria associated with impounded water. These activities have been greatly reduced in most States in recent years. Many States are now expressing considerable concern over the current expanding magnitude of vector problems associated with water resource developments. Most States, especially those in the West where extensive irrigation mosquito problems have developed, can only provide technical assistance on a limited part-time basis. The Bureau of Vector Control, California State Department of Public Health, employs a biologist to devote full time to vector problems associated with water resource developments. This is believed to be the only State that provides full-time technical assistance on this problem. Research activities are likewise extremely limited in most States. Two exceptions are California and Florida, both of which are carrying out various types of investigations related to the prevention and control of vector problems associated with water resource developments.

REQUIREMENTS FOR PROVIDING ADEQUATE PREVENTION AND CONTROL OF VECTOR PROBLEMS ASSOCIATED WITH WATER RESOURCE DEVELOPMENTS

The nature, extent, and importance of vector problems commonly associated with water resource developments and the basic prevention and control measures for these problems have been discussed in previous sections of this pamphlet. In order for maximum benefits to be derived from the Nation's water resources, the vast backlog of vector problems associated with existing developments must be brought under control as rapidly as possible, and adequate prevention and control measures must be planned and "built into" all future projects. The basic requirements for accomplishing these objectives are:

1. The agencies and groups concerned with the development and utilization of water resources, especially impoundments and irrigation, should have a basic knowledge of the importance of vector problems and their relation to water resource projects. In addition, they should recognize the need for coordinating and integrating vector prevention and control with the primary project functions during the planning, construction, and operational phases of their projects.
2. The sponsoring and/or operating agencies should accept full responsibility for the prevention and control of vector problems created by their projects.
3. The appropriate Federal, State, or local health agency should provide the construction and operating agency, group, or individual with detailed plans and specifications for vector prevention and control for individual water resource projects. The appropriate Federal, State, or local water resource agency should be responsible for seeing that the vector prevention and control measures are integrated into the project.
4. There should be continuous and close liaison and cooperation between the public health agencies and those concerned with the development and utilization of water resources.
5. For all Federal projects, legislation authorizing or providing appropriations for project construction and/or operation should provide adequate funds for building vector prevention measures into the projects at the time of planning and at the time of construction as well as funds for carrying out the necessary control measures after the project is in operation. Similar provision should be made for financing vector prevention and control measures for projects constructed and operated by State or local agencies. Administration of these funds for the specified purpose should be a designated responsibility of the project sponsor and/or operating agency.
6. Investigations should be made of possible ways and means whereby State or Federal agencies could provide additional financial assistance to local vector control programs, particularly for those areas which have sparse human population but extensive and widespread vector problems associated with irrigation or other water resource developments.
7. The irrigation and agriculture agencies should intensify their efforts to develop improved irrigation and drainage practices and to get them into use. At present, there is a tremendous gap between existing knowledge of good soil and water management practices and the application of this knowledge on irrigated farms. All-out efforts should be made to close this gap as

rapidly as possible, thereby eliminating mosquito sources, conserving water, and improving irrigation agriculture. Personnel of health agencies and local mosquito control organizations should cooperate in this effort.

8. In connection with the development of vector prevention and control measures for Federal water resource projects, there is a great need for a sound and effective program providing for (a) detailed field surveys and evaluations of vector problems associated with all proposed Federal water resource projects and the development of appropriate measures for preventing and controlling these problems; (b) adequate technical assistance to Federal, State, or local agencies on the control of vector problems arising from operating water resource projects; (c) adequate surveillance and followup surveys on the prevention and control measures which have been recommended for various types of projects; (d) close and continuous liaison with all other Federal agencies concerned with the development and utilization of water resources; and (e) research as needed to develop more effective vector prevention and control measures.
9. A major increase in research activities is urgently needed to solve the current backlog of vector problems associated with water resource developments and the new problems which are constantly arising. For some types of vector problems, it will be necessary to conduct investigations in the particular area in which they occur. Others may be solved by studies in representative areas and the results can be generally applied to comparable areas. Since many of the vector problems associated with water resource projects involve both public health and other interests, they can best be solved through joint investigations by the agencies concerned. Through such cooperative research, it will be possible to mutually accomplish the major objectives of the various groups.

GENERAL RECOMMENDATIONS

In order to minimize public health hazards associated with water resource developments, every possible effort should be made to avoid creating conditions which will increase populations of vectors of public health importance. It is therefore recommended that the following principles and practices for prevention and control of vector problems be adhered to in the design, construction, operation, and maintenance of water resource projects.

Impoundments

Practices leading to the prevention and source reduction of mosquito and other aquatic insect breeding sites include the following:

1. All borrow pits and other potential ponding areas associated with construction of the dam, relocation of highways or roads, etc., which are located above maximum pool level should be made self-draining.
2. Prior to impoundage, the reservoir basin should be prepared as follows:
 - a. The normal summer fluctuation zone of the permanent pool should be completely cleared except for isolated trees and sparse vegetation along abrupt shorelines which will be exposed to wave action.
 - b. Dense stands of timber rooted below the normal summer minimum pool level but extending above that level should be cleared. In some situations, such timber may be felled and securely tied down in lieu of disposal.
 - c. Borrow pits, depressions, marshes, and sloughs which will be flooded by the reservoir at maximum pool level and which would retain water at lower pool levels should be provided with drains to insure complete drainage or fluctuation of water within them.
 - d. If the summer fluctuation zone of the permanent pool is limited to a few feet, consideration should be given to "building out" mosquito-producing areas located within flight range of population groups or recreational areas through the use of measures such as deepening and/or filling. This would minimize the need for repetitive measures for controlling vegetation and mosquito production.
3. After impoundage, the following maintenance measures should be carried out in all potential mosquito-producing areas located within flight range of human population groups or recreational areas frequented by significant numbers of persons:
 - a. All dense vegetation should be removed periodically from flat, protected areas within the normal summer fluctuation zone of the permanent pool.
 - b. Vegetation, debris, and flottage should be removed periodically from all drains to insure free flows.
4. Water level management to minimize conditions favorable for mosquito production should be used to the maximum degree permitted by the primary purposes of the reservoir. This will minimize the need for repetitive measures for controlling vegetation and mosquito production.

5. As a general principle, waterside recreational areas, particularly those which have facilities for overnight human occupancy, should be located along sections of the reservoir which have a low production potential for mosquitoes and other aquatic insects of public health importance.

Terrestrial Arthropods and Rodents at Recreational Areas

1. Proper storage, collection, and disposal of refuse should be practiced in order to prevent and control flies, wasps, other noxious insects, rats, wild rodents, and other small mammals.
2. All buildings should be rodentproofed at recreational areas where rodents are prevalent which may create public health hazards.
3. Debris, rubbish, and other materials which may serve as harborage for rodents and other small mammals should be removed periodically.
4. Brush and weeds along paths, trails, roadways, and other areas frequently used by visitors should be removed in order to reduce the likelihood of tick infestation.

Waterfowl Refuges

1. Whenever possible, sites selected for waterfowl habitat development should not be within mosquito flight range of population groups or recreational areas.
2. Waterfowl areas which are to be flooded during the mosquito season should be diked or otherwise prepared with steep shorelines to preclude shallow water areas favorable for mosquito production.
3. Provision should be made for water level management in waterfowl areas which will minimize mosquito production.

Irrigation

Project Conveyance and Distribution Systems

1. Lining or other satisfactory seepage control measures should be provided for all sections of canals and laterals located in porous soil where excessive leakage would result in waterlogged areas, seeps, and ponds.
2. Drains should be installed to prevent ponding of excess irrigation water and natural runoff along the upper side of canals and laterals. All drainage crossing or inlet structures should be placed on grade to avoid ponding.

3. Borrow areas should be self-draining to keep them from retaining ponded water.
4. When possible, provision should be made to prevent turn-outs and other hydraulic structures from retaining residual water when they are not being used.
5. Effective measures should be provided to prevent ponding of leakage from water control structures.
6. Every effort should be made to establish delivery schedules which will provide farmers with adequate but not excessive amounts of water at proper intervals to insure efficient irrigation of the crops concerned.
7. Vegetation and debris which would retard normal flows should be periodically removed from conveyance channels, water control structures, and drains.

Project Drainage Systems

1. Trunk drainage systems should be installed to insure complete removal and proper disposal of excess irrigation water, natural runoff, and seepage from both irrigable and nonirrigable lands affected by the distribution and use of irrigation water on the project.
2. Drainage ditches should be designed, constructed, and maintained so as to minimize ponding in the channels and to insure free flows at all times.
3. Provision should be made to prevent water from ponding behind spoil banks.
4. Underdrains, culverts, inlets, etc., should be placed on grade to prevent ponding.

Irrigated Farms

1. The sponsoring agency and other organizations concerned with irrigation agriculture or mosquito control should encourage irrigation farmers to use the following irrigation and drainage practices which will prevent or minimize mosquito sources:
 - a. The farm supply system, drainage system, and field layouts should be properly fitted to the topography, soil, water supply, crops to be grown, and irrigation methods to be used.

- b. All surface irrigated fields should be properly leveled or graded to provide for efficient water application and removal of excess water without ponding.
- c. An adequate drainage system should be provided for removal of excess water from all portions of the farm.
- d. Irrigation methods should be used which will provide optimum irrigation efficiencies.
- e. Application of irrigation water should be limited to the amount required to fill the crop root zone plus water to cover unavoidable losses and excess water needed to prevent upward movement of salts.

Farm Ponds

- 1. The pond basins should be cleared of trees, brush, and other dense vegetation prior to impoundage.
- 2. Ponds should be constructed with steep banks to discourage growth of vegetation.
- 3. All dense vegetation should be removed periodically from shallow water areas.

Channel Improvements and Drainage

- 1. Borrow areas resulting from construction of the project should be made self-draining.
- 2. Material excavated from channels should be disposed of in such a way that it will not result in ponding of water.
- 3. Adequate drains should be installed to prevent ponding of water on berms or behind spoil banks, levees, and dikes.
- 4. Drainage ditches should be designed, constructed, and maintained so that they will concentrate low flows and reduce silt deposition and subsequent ponding, thereby insuring free flows at all times.
- 5. Underdrains, culverts, inlets, etc., should be placed on grade to prevent ponding.
- 6. Collection sumps should be constructed with steep side slopes, and any emergent vegetation should be removed periodically.
- 7. Sections of natural drainageways that are cut off or bypassed by new channels should be filled or provided with adequate drains.

8. Interior drainage facilities should be well maintained to avoid excessive ponding.

Waterways, Terraces, Floodways, Diversion Channels, and Drainage Ditches

1. Waterways, terraces, floodways, diversion channels, and drainage ditches should be designed, constructed, and maintained so that they will not retain ponded water or create ponded areas outside of the channels which would be suitable for mosquito production.

Supplemental Chemical Control Measures

In situations where adequate vector control is not obtained through prevention and source reduction measures, provision should be made for supplemental use of insecticides and rodenticides to achieve the desired level of control.

Routine Vector Appraisal

Arrangements should be made for carrying out a routine program of vector appraisal as a part of normal operations of the reservoir and associated recreational areas. Inspections for adult and larval mosquitoes and other vectors are essential for planning and evaluating control measures and for adjusting control programs to meet temporary or emergency situations.

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